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Unsupervised neural networks for clustering emergent patient flows

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ABSTRACT

In recent years, hospitals increasingly faced with a growing proportion of their inpatient admissions coming from the fluctuating demand of emergency admissions. The opportunity to move emergency patients, with a decision to admit, out of an Emergency Department (ED) is linked to the ability of the hospital to actually receive them. Indeed, the growing concern on public budget constraints implies reducing the number of inpatient ward beds making crucial to improve the bed capacity planning. The attention must be focused on avoiding system bottlenecks such as the boarding in the ED of emergent patients waiting to be admitted into inpatient hospital wards. Bed management is considered a critical function in managing bed capacity and smoothing elective and emergent patient flows. In order to support the bed management function the clustering and provisional analysis of patient flows data are needed. In this work, we use an unsupervised neural network technique, namely Self Organizing Maps (SOMs), to explore input data and to extract significant patterns. A large quantity of data records has been collected over a yearly period to obtain information related to the arrivals of emergent patients in a medium-sized ED located in the city of Genova. The aim of the paper is twofold. Our first goal is to develop a new framework based on SOMs for the analysis of healthcare data that include heterogeneous information. Second, we give a seasonal connotation to the analysed data, as the SOM can discover clusters and patient profiles that can be used to support bed capacity planning

1. Introduction and addressed problem

In recent years there has been a growing concern to reduce overcrowding in Emergency Departments (EDs) that is straightforwardly acknowledged being an issue of worldwide importance [1]. Many studies showed that the boarding of patients in ED hallways, when no inpatient beds are available, is one major cause of ED overcrowding. A "boarded patient" is defined as a patient who remains in the ED after a decision to admit in an inpatient ward, because no inpatient beds are available. The ED boarding often results in decreasing the ability to see new patients in the ED, increasing waiting time and length of stay, and leads to sufferings for those patients who wait, lying on trolleys in emergency department corridors for hours, and even days, as well as to the dissatisfaction of the emergency department staff.

The problem is further complicated by the current decrease of hospital beds due to financial concerns on public expenditure. In particular, Italy is the country in Europe with the lowest ratio of beds to population (about 3.4 per 1000 inhabitant vs. 6.3 European average, Eurostat 2014).

Facing ED boarding attains to recognize that it is necessary to manage the whole bed capacity considering emergent and elective admissions simultaneously to better smoothing intra-hospital patient flows from ED to inpatient wards.

The problem is not novel, and a solution suggested is the introduction of the so-called Bed Manager (BM) function within the hospital organization [2,3]. About twenty years ago, Green and Armstrong [4] already conceptualized the BM function as the way of "keeping a balance between flexibility for admitting emergency patients and high bed occupancy, which is an indicator of good hospital management".

The control of the whole set of patient flows is obviously possible only with the help of an on-line system able to identify earlier information about pending admissions to the acute beds available [5]. This can be done, for instance, visualizing the on time patient flows by means of a tool which collects and filters the information from the ED and inpatient ward thus supporting hospital bed managers in their daily decision making.

BM should be supplemented by other techniques and tools to allow classifying and clustering patients who arrive at the ED and forecast the demand of inpatients hospital beds coming from the ED.

In order to support the bed management function a deep data investigation aimed at classifying, clustering and predicting patient flows is needed.

In this work, we explore the potential of machine learning techniques to support the bed management function. As widespread

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known, machine learning [6] is a subset of computer science that deals with techniques and algorithms, based on empirical data, aimed to produce new knowledge on the observed phenomena. Data mining techniques can be used to learn the relationships between the critical features of the instances and the performance of algorithms [7]. The main goal is to learn as much as possible information from large amounts of data to support more informed decisions, and to transform new knowledge into an understandable structure for further use [8].

In particular, we use a kind of Artificial Neural Network (ANN), referred as Kohonen's Self-Organizing Maps (SOMs) to explore input data and extract significant patterns [9,10]. The main rationale for using SOMs over more traditional methods is the inherent local modelling property and the topology preservation of units that enhance interpretability of dynamics.

This study is developed with the collaboration of the Local Health Government of the Liguria Region (Italy) that help us to collect and analyse the main data related to the flows of patients in a medium sized ED sited in the city of Genova.

The paper is organized as follows. In Section 2 the main literature of interest is reviewed and the novelties of the study underlined. The methodology in use is introduced and explained in detail in Section 3 where the application to a real case study is also presented. In Section 4 the results are illustrated and discussed. Conclusions and future directions of research end the paper.

2. Literature review

As stated in the previous section, in this work we are focusing on ED boarding and overcrowding and the potential of bed management to address the problem and avoid bottlenecks in the patient flows. As a matter of fact, there is a wide variety of contributions dealing with those issues, either from a strongest mathematical viewpoint or in a more general quantitative perspective. Here we are mainly concerned in highlighting both the major points of contact between the earlier works on this topic and our paper, and the elements of novelty in our approach.

Starting from the evidence that ED boarding and access blocks can potentially represent a threat to patient safety, [11] developed a model of bed management based on features matching, in order to extract the similarities among various days. They extracted all days within the historical dataset that match the day type (Sunday, Monday, public holiday etc.) within a 4-week window, centred on the day of interest and applied a computational predictive model based on smoothing techniques as well as on multiple regression, and autoregressive integrated moving average models. Alternatively, [12] focused on the complexity of Emergency department (ED) as the key to analyse hospitals crowding. They then discussed a machine learning model which can identify the factors causing ED crowding and validate the coping strategies of hospitals. The model discussed in [12] first introduces the decision tree method to fit a nonlinear association and obtain intelligent grading rules of ED crowding; then it integrates the intelligent grading rules and indexes of coping strategies to construct a hierarchical linear model. The final outcome is a model, which is able to manage traditional modelling issue of high correlation among independent variables and un-convergence.

Furthermore, [13] examined various aspects of complexity and proposed a kind of theoretical lens for understanding and studying complexity in healthcare systems based on degrees of interrelatedness of system components. Along an inclusive research trail focusing on both the complexity of hospital procedures and the excellence of machine learning methods, there is also the contribution of Gopakumar et al. [14] where the authors compared the efficacy of five forecasting models to provide a reasonable estimate of total next-day discharges, which can aid in efficient bed management. The compared forecasting methods include Autoregressive Integrated Moving Average (ARIMA), Autoregressive Moving Average with Exogenous Variables (ARMAX) proposed by [15], *k*-nearest neighbour [16], random forest [17–19], and support vector regressions [20–22]. The challenge lies in dealing with large amounts of discharge noise introduced by the nonlinear nature of hospital procedures, and the unavailability of real-time clinical information in wards. The forecasting quality in this case was checked using mean forecast error, mean absolute error, symmetric mean absolute percentage error, and root mean square error [23]. Random forest and support vector regression models resulted in superior performance over traditional autoregressive methods. Similarly, Oliveira et al. [24] propose a Data Mining (DM) approach in order to identify relevant data about patients' management to provide decision makers with important information to fundament their decisions. The core of the procedure is a bunch of 48 DM models based on Machine Learning Models, namely: Regression Tree (RT) and Support Vector Machine (SVM) in order to perform regression tasks. Regression models were able to predict patient's discharges with very promising values of Relative Absolute Error (RAE). Joy and Jones [25], on the other hand, discussed a hybrid methodology, incorporating a neural network and an ARIMA model to predict a time series of bed demand, while Bagnasco et al. [26] highlighted the utility of artificial neural networks in predicting communication risks. Finally, Gul and Guneri [27] aimed to forecast patient Length Of Stay (LOS) using Feed Forward Artificial Neural Network (FFNN) within the input factors that are predictive such as patient age, sex, mode of arrival, treatment unit, medical tests and inspection in the ED.

Our work fits into the research vein that focus on the potential of machine learning techniques to deal with data mining and bed management issues. However, with respect to the existing literature, we add some elements of innovation.

A major element of novelty resides in the method used i.e. a kind of Artificial Neural Network (ANN) called Kohonen's Self-Organizing Maps [9,10]. It is known that in the plenty of learning machine algorithms, ANN are inspired by the functioning of the human brain to estimate unknown functions that depend on a large number of inputs [28,29]. Kohonen's Self-Organizing Maps (SOMs) are a particular kind of ANN using unsupervised learning to produce a low-dimensional (typically two-dimensional) map, that is a discretized representation of the input space [30]. SOMs have been largely applied in a variety of fields, including economic dynamics, accounting and financial reporting ([31,32], Peat and Jones 2014, [33]: the main strength of this approach relies on the possibility to extract intrinsic patterns, letting the data literally speaking from themselves [33,34]. Moreover, SOMs can be applied not only to numerical information, but also to qualitative data extracted from annual reports [35]. In general, although a large number of research papers agree that SOM is a very suitable technique to investigate financial data [36] and data mining in its wider broadest sense [37], to the best of our knowledge, there is any paper directly applying SOM to support bed management strategies.

This paper aims at filling this gap suggesting a pilot case study for further developing a more consolidated framework for the use of SOMs to similar problems. More in details, our work fits in the existing literature by contributing towards at least two directions:

first, developing a new framework for the analysis of healthcare data, using SOMs as source of heterogeneous information; second, giving a seasonal connotation to the analysed dataset, as the SOMs can be used to discover clusters and patients' profiles that can be used to support hospital and bed management policies.

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